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# Improvement of Well Test Equipment in Olkaria Geothermal Field

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## ABSTRACT

Geothermal wells are discharge tested after drilling to capture important parameters such as steam and brine output, enthalpy, discharge wellhead pressure and characteristic fluid chemistry at different throttle conditions. These parameters are useful in estimating the power capacity of a well, and for the design of the geothermal power plants and associated steam field infrastructure. The geothermal field in Olkaria is liquid dominated, producing both steam and liquid at the wellhead, which must be separated during a well discharge test. The silencer/separator is used to separate these two phases where the liquid phase is known as brine because it contains mineral salts and other dissolved solids. Noise is generated by conversion of kinetic energy into noise by sonic expansion of steam in the silencer/separator causing turbulence as a result of mixing high velocity mass flow with quiescent air.

Wellhead silencers have been undergoing improvements on both separation efficiency and noise reduction since the start of geothermal development in Olkaria. The current silencers used for well testing causes noise generation of more than 107 decibels which is way beyond allowable noise limits for industrial and commercial areas in Kenya. This has predisposed KenGen to conflicts with local community and Kenya Wildlife Service (KWS) who are our stakeholders in Olkaria. Furthermore, these conflicts have resulted in delays in testing drilled wells therefore affecting the field development plans.

The silencer must be designed to achieve two requirements; efficient separation of the two phase flow and to attenuate the noise generated to acceptable limits. The design approach in this study is to handle the two challenges separately, by using a lower separation unit and an upper silencing unit. Based on the cyclone and the gravity separation principle, two prototypes were designed and tested. Both separator/silencers achieved permissible noise levels for industrial and commercial areas at the well pads with better brine separation efficiencies.

## 1. INTRODUCTION

Geothermal power plants are designed based on the chemistry and characteristics of wells obtained by carrying out well tests after drilling. These parameters are important in estimating the power capacity of a geothermal well as well design of associated steam field and later in the management of these systems. Several accurate methods are available for carrying out these measurements, which are complex and require use of heavy equipment and instrumentation. These test equipment may be uneconomical for carrying out well tests for a short period.

Russel James developed a fairly accurate, easy and economical method in 1965 for carrying out flow measurements called the James lip pressure method. When a large flow of compressible fluid such as steam-water mixture flows along a pipe towards a region of low pressure (atmosphere), the flow velocity is sonic on exit. The pressure along the pipe falls to a value above atmospheric at the discharge point. This discharge pressure is directly proportional to the flow rate and stagnation enthalpy of the flowing liquid. The method involves use of water separator to separate the liquid phase from the steam phase and a weir box to measure brine flow.

The Olkaria geothermal field is a liquid dominated reservoir and the Russel James lip pressure method is used for well testing. The sonic expansion of water-steam mixture at the lip pipe causes aerodynamically induced noise, which need to be reduced to conform to environmental regulations.

### 1.1 Impacts Associated with Noise

The Olkaria field is located in a national park where there are stringent noise regulations. It is also located in proximity to the local community and noise from well testing has been a source of conflict between KenGen and the local community. These conflicts has caused delays in the past in testing wells and hence affecting the field development plans. The current silencers used for well test are inefficient in suppressing the noise and therefore there is need to improve noise attenuation. The impacts associated with noise in the Olkaria geothermal field falls into three categories as socio-economic effects, health effects and the effect on wildlife.

#### 1.1.1 Socio-Economic effects

- Depreciation of property value
- Penalties for violating laws & regulations, i,e EMCA Cap 387 for Kenya

- Work/project stop orders by industry regulators and associated loss of revenues
- Community agitations
- Human resettlements, migration/immigration and associated disturbance costs
- Accidents at the workplace
- Litigation costs on disputes relating to noise emissions

1.1.2 Health effects

- headaches and stress
- poor concentration,
- productivity losses in the workplace
- communication difficulties
- fatigue from lack of sleep
- cardiovascular implications
- cognitive impairment
- tinnitus
- hearing loss

1.1.3 Effects on Wildlife

- Animal agitation and human attacks
- Migration/immigration if wildlife
- Loss of wildlife habitats
- Change of animal behavior e.g eating habits, aggressiveness

## 1.2 Applicable Laws, Regulations in Kenya on noise Pollution

1.2.1 Environmental Management and Coordination Act (EMCA), Cap 387

EMCA is an Act of Parliament that establishes legal and institutional framework for the overall environmental management in Kenya. Key subsidiary regulation of EMCA in regard to noise emission is the Environmental Management and Coordination (Noise and Excessive Vibration Pollution Control) Regulations, 2009. These regulations provides measures to control excessive noise emission and vibration associated with various activities be it temporary or long lasting. The aim is to prevent annoyance, disturbance, adverse psychological or physiological effects on persons, or damages to property in the neighborhood. Noise emission limits as provided in EMCA-Cap 387 are indicated in table 1 below.

**Table 1: Noise emission limits as provided by EMCA**

| Receptor/ zone | Max. Permissible Sound level limits in dB(A) | |
|---|---|---|
| | Day (6:01am to 8:00 pm) | Night (8:01pm to 6:00am) |
| Residential indoor | 45 | 35 |
| Residential outdoor | 50 | 35 |
| Mixed residential (with some commercial & places of entertainment | 55 | 35 |
| Industrial & Commercial | 60 | 35 |

1.2.2 Environmental Management and Coordination Act (EMCA), Cap 387

Jurisdictions such as European Union (EU) and institutions including WHO also provides guidelines and standards on management of air quality and noise emission. Noise emission limits as provided by WHO are shown in table 2 below.

**Table 2: Noise emission limits as provided by WHO**

| Receptor/ zone | Max. Permissible Sound level limits in dB(A) | |
|---|---|---|
| | Daytime (0700-2200hrs) | Night time (2200-0700hrs) |
| Residential, institutional & educational | 50 | 45 |
| Industrial & commercial | 85 | 85 |

1.2.3 The Factories and Other Places of Work (Noise Prevention and Control) Rules, 2005

The Factories and Other Places of Work Act, 2005, applies when conducting environmental and occupational noise impact assessments in addition to regulations provided by EMCA, Cap 387. The Act stipulates exposure within the workplace should not exceed 85.0 dB(A) for industrial facilities.

## 2. SEPARATOR/ SILENCER DESIGN

The first separator/silencer design in Olkaria was made of concrete which had very low separation efficiency and risky to personnel and animals because the inlet was made of large culverts. This resulted in anything near the inlet being sucked into the silencer, which is a potential hazard to personnel working in the field as well as animals nearby. The next generation of silencers was a tangent inlet type which were both inefficient in separation and noise reduction. The present type of silencers is the twin silencer that has been in use for a long time in Olkaria for well testing and they are efficient in steam/brine separation. With the accelerated geothermal field development in Olkaria, wells located in noise sensitive areas have been drilled and these silencers are found to be inefficient in noise reduction.

The design procedures followed are as a result of review of literature sources and accepted industrial design guidelines. The design involves optimizing the length and diameter by minimizing the weight of the shell and height. The design approach is to treat the steam/brine separation and the noise reduction separately resulting in the design of a lower separator unit and an upper silencer unit. Fluid separation is achieved in two stages. Primary separation stage uses an inlet diverter so that the momentum of the fluid entrained in the vapor causes the largest droplets to impinge on the diverter and then drop by gravity. The second secondary stage is the separation of the smaller droplets by gravity as it moves along the disengagement area.

### 2.1 Separator Section Design

Three principles used to achieve physical separation of gas and liquids or solids are momentum, gravity settling, and coalescing. Two-phase separators are either on horizontal or vertical orientation on installation depending on the vapor liquid ratio of the mixture to be separated. Vertical separators are preferred for mixtures with high vapor to liquid ratios whereas horizontal separators are preferred for mixtures with lower ratios. Liquid separation is achieved in two stages with the first being primary separation where the flow impingement of the flow on a diverter causes larger droplets to fall by gravity, the second stage is secondary separation where smaller droplets fall by gravity as the flow advances on the impingement area.

2.1.1 Steam Gravity Separation

Liquid droplets will settle out of a gas phase if the gravitational force acting on the droplet is greater than the drag force of the gas flowing around the droplet. The maximum allowable velocity for gravity separation must be calculated so that the liquid disengagement area can be adequately determined. The steam gravity separation can handle steam with a high liquid loads and has two main functions; that is reduction of entrained liquid load not removed by the inlet expansion and the smoothening of the steam velocity profile.

2.1.2 Separation Theory

Considering a brine droplet of diameter, Dp in the steam phase; two forces act on the droplet. First is the gravitational force $F_G$ exerted by the weight of the droplet and drag force $F_D$ exerted by the steam flow. The drag force acts to entrain (carry-over) the liquid droplet whereas the gravitational force pulls it down to separate the liquid droplet from the gas phase.

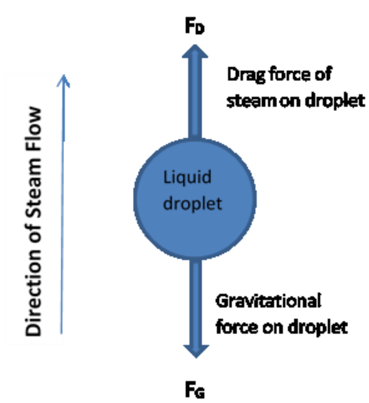


**Figure 1: Forces acting on a liquid Droplet.**

$$\text{Drag force; } F_D = \frac{C_D A_P \rho_L V^2}{2 g_c} \quad (1)$$

$$\text{Droplet projected area; } A_P = \frac{\pi D_P{}^2}{4} \quad (2)$$

$$\text{Gravitational force; } F_G = \frac{(\rho_L - \rho_p)\, V_D g_c}{g} \quad (3)$$

$$\text{Volume of spherical droplet; } V_D = \frac{(\pi)}{6}\; D_P{}^3 \quad (4)$$

Where $C_D$ Drag coefficient, AP droplet projection area, v steam velocity, ρl liquid density, $g_c$ correction factor, DP droplet diameter, VD droplet volume and $\rho_v$ steam density.

Assuming the velocity of fluid to be constant across any cross section (plug flow); with no eddies or disturbances and ignoring end effects; the two forces are equal at equilibrium; $F_D = F_G$.

Substituting for $F_D$ and $F_G$ and solving for maximum allowable vapor velocity $V_T$ which prevents liquid entrainment is given by;

$$V = \left(\frac{4 g D_P}{3 C_D} X \frac{\rho_L - \rho_V}{\rho_V}\right)^{1/2} \quad (5)$$

Substituting the first term with design (sizing) parameter $K = \left(\frac{4 g D_P}{3 C_D}\right)^{1/2}$

$$V = K \left(\frac{\rho_L - \rho_V}{\rho_V}\right)^{1/2} \quad (6)$$

This equation is referred to as the Souders-Brown equation. The terms $\rho_V$ and $\rho_L$ are the gas phase and liquid phase densities, respectively.

The design parameter, K, in the Souders-Brown equation is an empirical parameter and is a key factor for the sizing the vapour-liquid separators vessel diameter. Its value depends on several factors including:

- Pressure
- Fluid properties
- Separator geometry
- Steadiness of flow
- Inlet design and performance
- Relative amounts of steam and liquid

### 2.1.3 Vertical separator design

The first step in silencer design is the determination of the terminal velocity using Sauders Brown equation to calculate the disengagement area. The K value is a function of pressure and there are several literature that estimates the K values used for separator design. In this particular design, K values used are the ones specified in the Gas Processors Supplier Association (GPSA) Engineering Data book. The allowable vertical velocity for droplet settling to occur is equal to the terminal velocity. The allowable vertical velocity is 0.75 times the terminal velocity for a conservative design. The hold time is the time required to reduce the water from normal liquid level to low liquid level (empty) while maintaining normal outlet flow that is important during operation so that steam does not escape through the weir box during well test. The surge time is the time required to increase the water level from normal liquid level to maximum liquid level while maintaining the normal feed without outlet flow. This is also important to avoid brine from rising above the fluid entry level, which adversely affects the separation efficiency. For vertical separators, the vapor disengagement area is the entire cross sectional area of the vessel and the diameter is determined from the equation $D=4Q_V/\pi U_v$ , where $Q_v$ is the vapor volumetric flow rate, D is the vessel diameter and $U_v$ is the vertical velocity. Then the corresponding cross sectional area, A is determined. The next step is to determine the vapor disengagement height.

2.1.4 Horizontal separator design

The horizontal two-phase separators are occupied by both steam and liquid on the cross sectional area and for design purposes, the width and height are assumed and the normal liquid level is set by liquid hold up while the high liquid level is set by liquid surge. The vapor disengagement height is the height required for the liquid droplet to separate from the vapor and the vessel length is calculated to accommodate liquid surge and hold up or vapor disengagement. The vapor volumetric flow rate and liquid volumetric flow rate are then calculated. Surge time and hold up time is taken as 10 and 5 minutes respectively and the hold up volume and surge volumes are calculated.

The design pressure is equal to operating pressure + (15-30 psi) which whereas the design temperature is taken as the saturation temperature at +40 $^0$F. Since corrosion is expected due to acidic gases, ASTME SA 516 Grade 7 material is selected. The allowable stress is 17500 psi and the shell thickness calculated.

## 2.2 Silencer section design

Silencers are devices designed to attenuate and absorb air-born sound waves propagated in a flowing medium. There are three types of silencers used for noise attenuation.

- Absorptive
- Reactive
- Dispersive

The main consideration in designing silencer units for geothermal application is to design a silencer that creates little backpressure as much as possible while meeting noise level requirements. The silencer section is designed to reduce noise emitted by two methods. The first is reactive silencing where noise is reduced by reflection while the second noise reduction mode is by use of noise absorbing materials.

2.2.1 Absorptive silencer design

This silencer type uses absorptive materials to attenuate the sound waves. The thickness of acoustic linings should be selected according to the most dominant frequency of the noise to be absorbed. The incident sound energy is partially transformed into heat as it moves along the absorptive material. In Absorptive silencer design, various types of fibrous packing materials effectively absorb noise energy; the resulting viscous friction dissipates the sound energy as small amounts of heat. The main applications of absorptive silencers are absorption of the high frequency noise. Different packing materials can be used in absorptive silencers and chosen for use based on varying absorptive performance, price, temperature and corrosion resistance characteristics. Absorptive silencers are made of perforated tubes lagged with noise abortive materials.

Lined elbow section

A lined bend improves sound attenuation by forcing sound energy through a corner. The walls are lined with sound absorbing materials, sound energy is forced to impinge on the sound absorbing surface as it reflects its way around the corner; each successive impingement takes sound energy from the travelling wave. A lined bend is acoustically effective when it extends at least three times the inlet diameter.

Expansion section

The separation unit acts as a plenum chamber for noise reduction. The expansion section is lined with sound absorbing materials that absorb most of the sound energy when it is reflected back at the walls of the chamber.

2.2.2 Reactive or Reflective Silencer Design

This consists of expansion chambers where the inlet opens into a large volume creating an abrupt change in cross sectional area at each end of the volume. The primary function of this type of design is to reflect sound wave back to the source. Energy is dissipated from extended flow path resulting from internal reflections and by absorption at the source. Reactive silencers are effective for high frequency attenuation. The length of the chamber is adjusted so that reflected wave cancels the incident wave.

Transmission loss through an expansion chamber is the difference in sound pressure level of the incident sound wave and the transmitted sound pressure level. The length of the chamber controls the frequency at which there is maximum attenuation and increasing the mean flow velocity through the muffler up to 30 m/s increases the transmission loss. Large chamber walls should be avoided because they vibrate and radiate noise.

2.2.3 Dispersive silencer part

The silencers reduce the fluid pressure, reduce the velocity, and straighten the flow reducing turbulence, which is the source of aerodynamically induced noise. The flow sound intensity is proportional to the eight power of the jet velocity and small reduction in velocity results in large reduction in noise.

## 3.0 RESULTS

### 3.1 Separator Design

Several wells were chosen across the entire Olkaria field based on the flow rates of both steam and brine to capture well discharge parameters representing any discharge conditions that may be encountered during well discharge tests. Ten wells were therefore chosen for design including the biggest wells that have been drilled in Olkaria. The vessel diameter ranges from 2 to 6.1 m controlled by the steam volumetric flow rate whereas the total vessel diameter ranges between 1.9 and 6.4 m. The main challenge for separator design for well discharge test is to design a silencer that can economically handle wells with big variations in steam and brine volumetric flow rates. The diameter of the vessel is therefore chosen as 3.6 m based vessel diameter values which can handle several wells and can be conveniently transported from well to well as well as on Kenyan roads standards.

Vessel total height ranges from 2 to 7 m with most wells having 2 m. The design height of 4 m was settled upon constrained by installation stability during discharge tests. The silencer size handles most of the wells in Olkaria, whereas a well with total height greater than 4 m means use of more than one separator.

For gravity separators, height of vessel is calculated from the surge volume and hold up volumes and it varies between 0.5 and 3.3 m. The length L varies between 2.7 to 8.4 m while minimum length for liquid droplet separation $L_{MIN}$ is between 2.1 and 26.6 m. If $L< L_{MIN}$ then L is set at $L_{MIN}$ meaning vapor/liquid separation is controlling and if $L> L_{MIN}$; the design is acceptable for liquid separation.

Considering transportation efficiency, L and $L_{MIN}$, the vessel height is set at 2 meters. Height varies between 0.1 and 17.1 m and $L_{MIN}$ between 2.2 and 10.5 m. Comparing L and $L_{MIN}$ results in design length for each well with lowest being 3 m and the highest is 10 m. To accommodate several wells in Olkaria, the vessel length is therefore set at 12 m.

### 3.2 Silencer Section

Silencer design section was done by reviewing the design of the current silencers that are not efficient enough in noise attenuation. It involved first identification of the sources of noise in the current silencers that was identified as follows:-

- Inlet noise generation
- Noise emitted from the walls of the silencers
- Emission of noise at the silencer outlet

#### 3.2.1 Inlet Spool

The inlet spool is made long enough to make flow as laminar as possible and diffuse noise by reducing turbulence that is a source of noise. The inlet was also covered to reduce air suction which causes noise as well as low fluid separation efficiency. It also provides for noise reduction by expansion from the lip pipe cross section to a bigger volume causing reactive noise cancellation. The dissipated noise was reduced by lagging the inlet with fiberglass material that absorbs the noise. Fiberglass was particularly chosen as a lagging material because of the following properties:-

Chemical resistance- Fiberglass textile fabrics will not rot, mildew or deteriorate. They resist most acids with the exceptions of hydrofluoric acid and phosphoric acid.

Dimensional stability- Fiberglass fabrics will not stretch or shrink. Nominal elongation break is 3-4 percent. The average linear thermal expansion coefficient of "E" glass is 5.4 by 10.6 cm/cm/°C.

Good thermal properties- Fiberglass fabrics have a low coefficient of thermal expansion and relatively high thermal conductivity. Glass fabrics will dissipate heat more rapidly than asbestos or organic fibers.

High tensile strength- Fiberglass yarn has a high strength-to-weight ratio. Fiberglass yarn is twice as strong as steel wire.

High thermal endurance- Fiberglass cannot burn and is unaffected by curing temperatures used industrial processing. Fiberglass will retain approximately 50 percent of its strength at 700°F and as much as 25 percent at 1000°F.

Low moisture absorption-Fiberglass yarn has extremely low moisture absorption.

Cost-effective- Fiberglass fabrics offer cost advantages compared to other synthetic and natural fiber fabrics.

#### 3.2.2 Separator and silencer walls

The separator section acts as both reactive and dissipative silencer for noise attenuation. The separator section acts as a reactive noise reducer by providing an abrupt change in inlet cross section which is effective in the high frequency noise band attenuation. Double walls are also used where 200 mm thick fiber glass material is stuffed in between to absorb the noise and avoid wall emission.

3.2.3 Silencer unit

The silencer unit is designed as an absorptive silencer to reduce noises emitted at the outlet and increase noise transmission losses that are effective in low frequency noise attenuation. Stainless steel perforated tubes and panels are stuffed with fiberglass and rapped with fiberglass cloth to avoid erosion of the by steam. To improve the noise absorption efficiency, the silencer unit is made as long as possible where a minimum length of 2.5 meter was used as well as minimum fiber thickness of 200 mm, perforations of over 40% open area and fill density greater than 100 kg/m$^3$.

### 3.3 Separator/Silencer Test results

After the design was completed, the silencers were fabricated taking into consideration the design details. OW-49C was used for testing prototype 1 (cyclone separator/silencer) and OW-736C for prototype 2 (gravity separator/silencer). For OW-49C, the old silencer was tested first before installation of the new improved cyclone separator/silencer but for OW-736C, the improved gravity separator/silencer was installed and tested first.

3.3.1 Cyclone Separator/Silencer Prototype test results

The test results for the improved cyclone separator/silencer are shown in figure 2 to figure 5 below. Figure 2 below is a plot of noise measurement against distance from the silencer for the improved cyclone separator and the old cyclone type silencer/separator. The results shows that the highest recorded noise for the improved cyclone separator/silencer is 75 decibels at the silencer whereas the highest recorded noise for the old cyclone separator at the same location is 99 decibels. Moving just 10 m from the silencer the highest recorded noise for the improved separator/silencer is around 61 decibels while the old silencer noise measurement at the same point was around 95 decibels. At 100 m from the silencer, 60 decibels was recorded for the improved cyclone separator/silencer as compared to 83 decibels for the old cyclone separator. The results shows decreasing noise levels as you move away from the silencer for both types of silencers. There was no change in noise measured after around 800 m for both silencers and no difference in noise measured for the two types of silencers. Figure 3 below shows a plot of the measured brine flow verses well head pressure at 8" and 6" lip pipe throttled conditions. Figure 4 is a plot of the total mass flow from the well against wellhead pressure while discharging at 8" and 6" lip pipes.

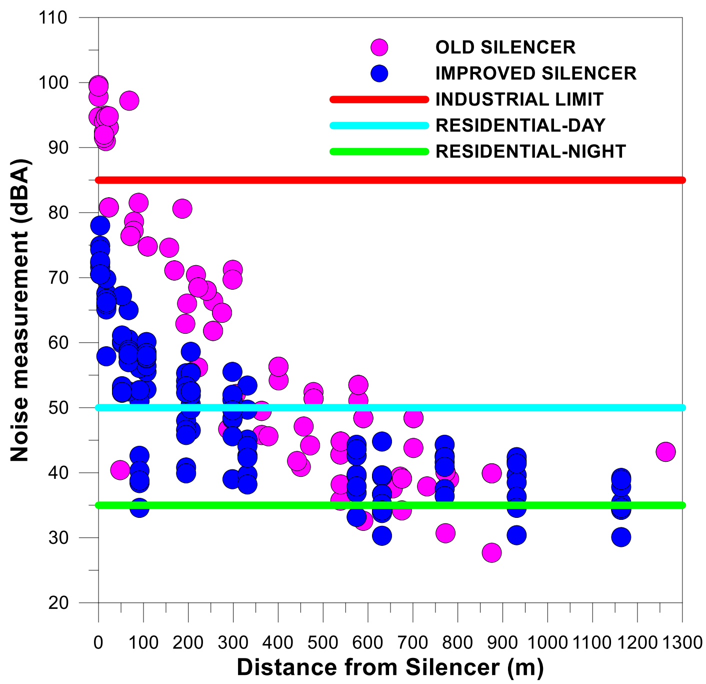


**Figure 2: Plot of Noise Measurement against Distance from Silencer.**

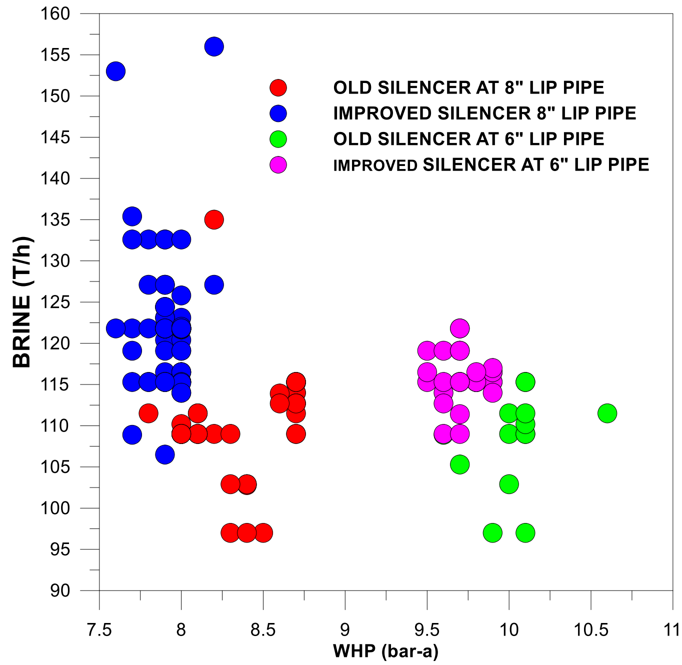


**Figure 3: Brine Flow Verses Well Head Pressure.**

The results shows that higher brine flow was measured for the improved cyclone separator/silencer as compared to the old silencer at the same wellhead pressure while discharging at both 8 and 6". The old silencers recorded a generally higher wellhead pressures as compared to the newly improved silencer. Both silencers recorded a decrease in brine flow as you discharge the well at an increased throttle condition by changing the lip pipe from 8" to 6". The total mass flow was slightly higher for the improved cyclone separator/silencer as compared to the old silencer for both 8 and 6" lip pipe. There was a reduced total mass flow for both separator/silencer as you change the lip pipe from 6 to 8".

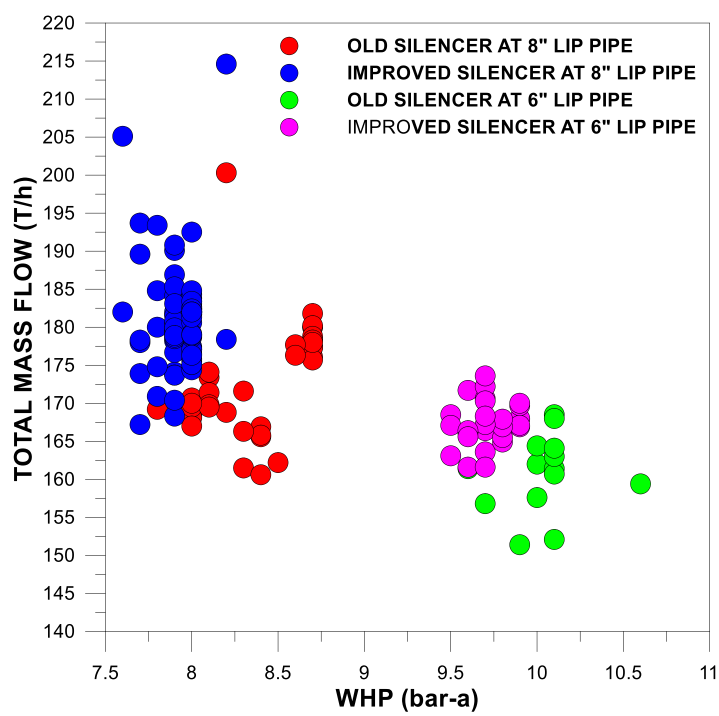


**Figure 4: Total Mass Flow Verses Well Head Pressure**

Figure 5 below shows a plot of steam flow verses wellhead pressure while discharging on both 8" and 6" lip pipes. The plots show increased steam supply for the old separator/silencer as compared to the new separator/silencer while discharging on both the 8 and 6" lip pipes for both the types of separator/silencers. The is a general decrease in steam flow rate for both types of silencer/separator as you change the pc from 8 to 6".

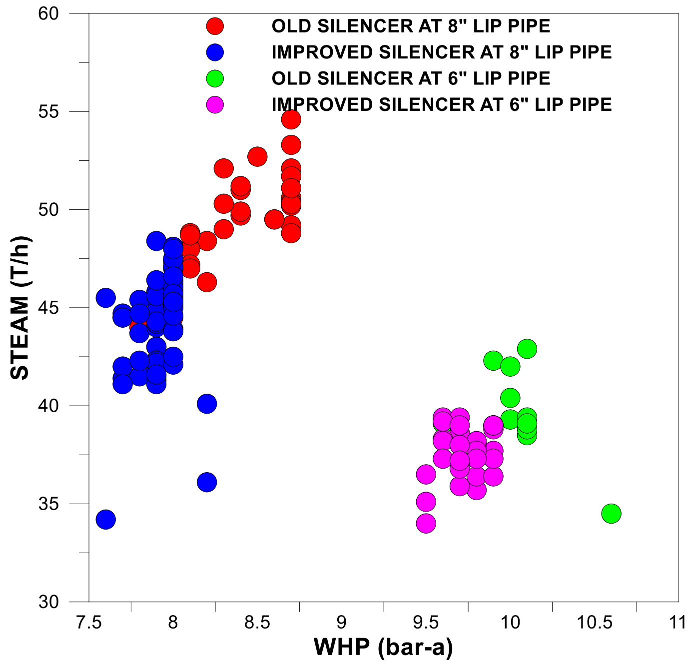


**Figure 5: Steam Flow Verses Well Head.**

<u>3.3.2 Gravity Separator/Silencer Prototype</u>

The test results for the improved gravity separator/silencer are shown from figure 6 to figure 9. Figure 6 below is a plot of noise measurement against distance from the silencer for the improved gravity separator and the old cyclone type silencer/separator. The results shows that the highest recorded noise for the improved gravity separator/silencer is 84 decibels at the silencer, 74 decibels at 10 m from silencer and 65 decibels at 100 m from silencer. A measurement of 53 decibels is captured at around 200 m from the silencer and 60 decibels at 300 m. The results shows decreasing noise levels as you move away from the silencer up to around 700 m from the silencer where 55 decibels is measured. There was no change in noise measured beyond 700 m and up to the total distance from the silencer of 1800m.

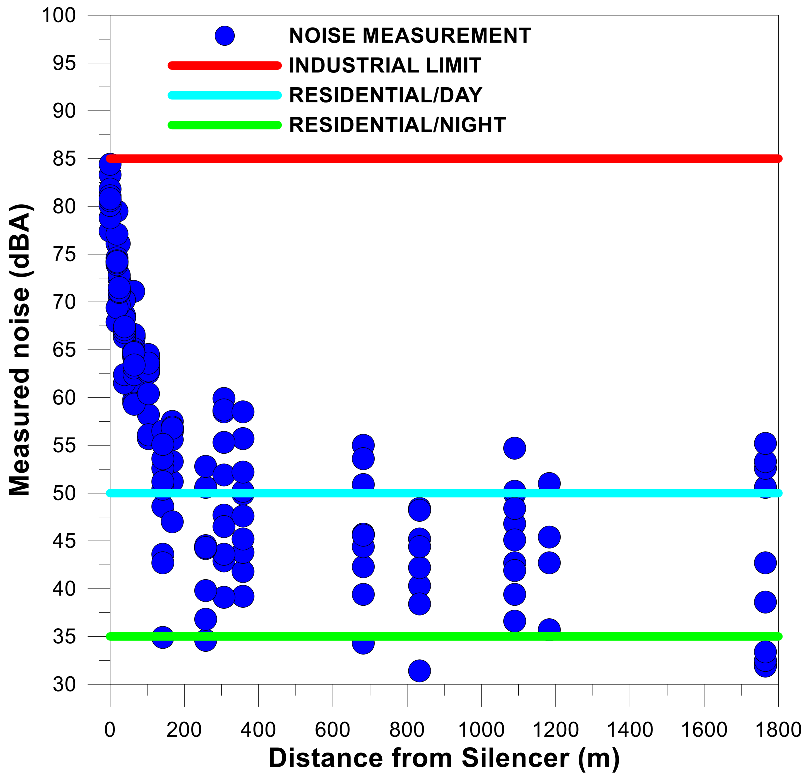


**Figure 6: Plot of Noise Measurement against Distance from Silencer**

Figure 7 below shows a plot of the measured brine flow verses wellhead pressure at 8” and 6” lip pipes throttled conditions. Figure 8 is a plot of the total mass flow from the well against well head pressure while discharging at 8” and 6” lip pipes. The results shows a slightly higher brine flow for the improved cyclone separator/silencer as compared to the old silencer at the same wellhead pressure while discharging at both 8” and 6” lip pipes. The wellhead pressures were comparably same for both types of separator/silencers. Both silencers recorded a decrease in brine flow as you discharge the well at an increased throttle condition by changing the lip pipe from 8” to 6”. The total mass flow was slightly higher for the improved cyclone separator/silencer as compared to the old silencer for both 8 and 6” lip pipe. There was a reduced total mass flow for both separator/silencer as you change the lip pipe from 6" to 8”.

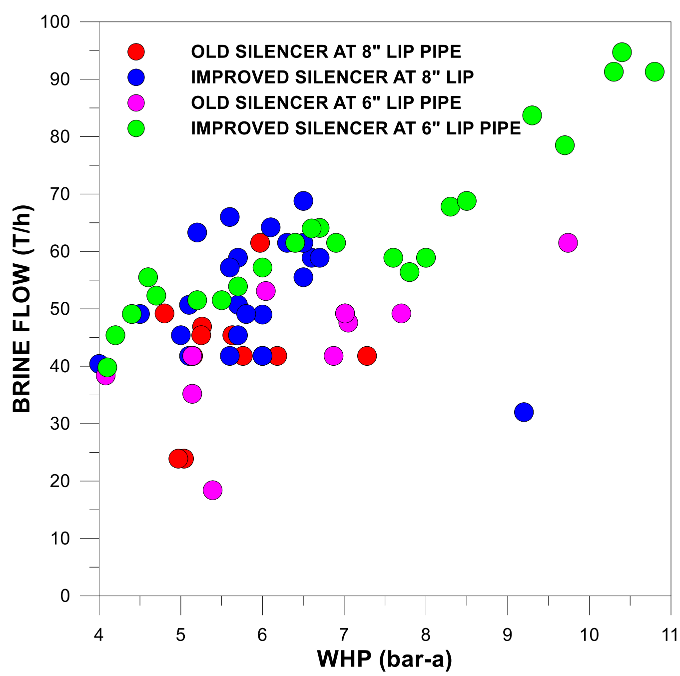


**Figure 7: Brine Flow Verses Well Head**

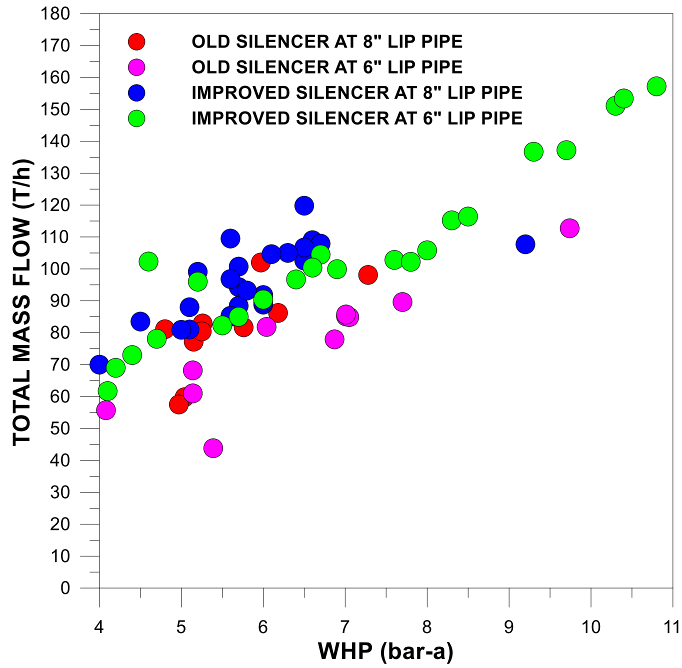


**Figure 8: Total Mass Flow Verses Well Head**

Figure 9 below shows a plot of steam flow verses wellhead pressure while discharging on both 8" and 6" lip pipes. The plots show same amount of steam flow for both the separator/silencers at the same throttled condition. There is a general decrease in steam flow rate for both types of silencer/separator as you change the pc from 8 to 6".

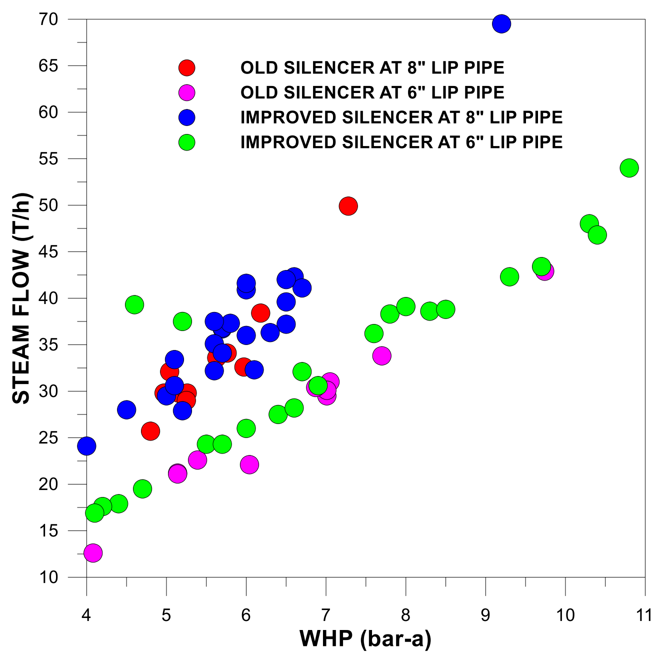


**Figure 9: Steam Flow Verses Well Head**

## 4.0 DISCUSSIONS

### 4.1 Cyclone Separator/Silencer Prototype

The improved cyclone separator/silencer design test results showed very good noise attenuation as compared to the old separator/silencer. The maximum-recorded noise level of 75 decibels at the silencer is much lower than 99 decibels for old separator/silencer and lower than the 85 decibels required in the workplace noise limits. At about 10 m from the silencer, the noise is 60 decibels, which means that the improved cyclone separator/silencer is within the limits of noise regulations in the workplace. Workers at the well pad are able to communicate audibly which is important in reducing accidents and incidents at the well pad. The daytime residential limit of 50 decibels compliance is possible at 300 m from the improved cyclone silencer separator while for the old silencer this limit is achieved after 750 m from the silencer. This means that wells nearer to the local community can be safely discharge tested by using the improved separator/silencer without conflicts with the local community and environmental pollution regulators. There was no further reduction in noise after 650 m from the silencer meaning that noise measured beyond this point is controlled by background noises from other discharging wells. Comparison of brine discharge from the two separator/silencers shows that the brine flow measured from the improved separator/silencer is higher than the brine flow the old silencer. This means that the improved separator/silencer separated more brine from the flow than the old silencer suggesting better separation efficiency. The higher wellhead pressures from the old silencers than the improved separator/silencer means that we have a sizing issue with these silencers.

### 4.2 Gravity Separator/Silencer Prototype

The noise testing for the old silencer is not yet done and therefore the noise test results are not available. However the results from the improved separator/silencer test shows a maximum of 84 decibels at the silencer which reduces to around 58 decibels at 100 m from the silencer. This shows that the noise levels while discharging wells using this silencer is within the industrial noise regulation limits at the well pad. There is no change in noise measured after 250 m from the silencer during this test, which is a strong indication that the background noise is controlling noise levels in this well pad. One explanation for this is that OW-740A was discharging vertically at the time of this test and could not be shut due to well control issues. The higher noise levels of 84 decibels at the silencer maybe attributed to leakage from OW-736, which is 10 m away, and located at the same well pad as OW-736A where the noise testing was done.

The flow test for OW-736C shows wide variation of well head pressure under the same throttled conditions which is a sign of high discharge cyclicity from the well. There is no observable change in well head pressure when the well is discharge tested using the different types of silencers which may show that both silencers are correctly sized for this well. Brine flow from the well shows that there is slightly higher flow when tested using the improved separator/silencer than flow from the old one. This is an indication of a better brine/steam separation with the improved silencer and therefore a better efficiency.

## 5.0 CONCLUSION

Noise emissions remain a critical issue while discharge testing geothermal wells and therefore there is need to improve on discharge test equipment used currently in Olkaria. A part from reducing the impacts associated with noise pollution on the personnel working at the wells as well as the stakeholders within the geothermal area, improved noise attenuating silencers reduces delays in well testing of future wells and therefore enabling the company to meet field development targets. The following conclusions is made with regard to the improved well test equipment in Olkaria:-

- Noise reduction is achieved by use of the improved silencers which is within the limits of noise regulatory authority and that the silencers can be used in wells located in closer proximity to the local community without violations of these regulations.
- The new well test equipment has enabled testing wells in noise sensitive areas, which was not possible in the past and maybe used in future in areas other with similar stringent noise regulations.
- Better separation efficiencies is achievable with this new well test equipment ensuring the reliability of the data collected.
- Due to increased background noises in OW-736C well pad and its vicinity, it is recommended that the gravity separator/silencer prototype be tested also on well OW-49C. This would give an opportunity to compare the performance of the three types of silencers and assist in making decision on the best design to adopt for well testing in Olkaria.

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